United States Department of Agriculture
Agricultural Research Administration
Bureau of Entomology and Plant Quarantine

PROTECTING STORED SEED FROM INSECT ATTACK

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The protection of seed from insect attack is of considerable importance to the seedsman faced with the problem of preserving bulk seed in storage prior to packaging and surplus seed that must be carried over from one season to another. Stored seeds provide a supply of concentrated food that constitutes an ideal diet for a large group of insects known popularly as stored-produce insects. These insects have adapted themselves to living on foods low in moisture content without recourse to other sources of moisture. The germ of the seed, with its high food value, is particularly attractive to these insects. Therefore, its destruction is often the first injury resulting from the attack of such species as the Indian-meal moth (Plodia interpunctella (Hbn.)), the cadelle (Tenebroides mauritanicus (L.)), or the flat grain beetle (Laemophloeus minutus (Oliv.)).

Information on the protection of seed from insect damage is by no means complete. However, the increasing demand for information on this subject makes it desirable to present the best information available at this time.

Factors Affecting Development of Grain Insects

To preserve the viability of seed for the longest possible time, it should be kept in a dormant condition. High moisture content and high temperature speed up the life processes of seed and unduly shorten the period of viability. For this reason the fundamental requirement for the preservation of seed is low moisture. Low temperature is also helpful but not indispensable.

The same factors that speed up the life processes of the seed similarly affect the seed-infesting insects. Within certain limits, the higher the moisture content of the seed and the higher the temperature the faster these insects reproduce. Seed that is cool, dry, and free from dockage (dust or broken kernels) is unfavorable for insect development.

The rice weevil (Sitophilus oryza (L.)) and the granary weevil (S. granaria (L.)), the most serious pests of stored grains, cannot breed in seed with a moisture content of 8 percent or less, and they soon die if restricted to such seed for food. Mites, which are not true insects but are usually classed with this group of seed pests, require food with a rather high moisture content; they are not troublesome in seed unless the moisture content is above 12 percent. Moths such as the Indian-meal moth and the Mediterranean flour moth (Ephestia kuehniella Zell.), insects of the bran beetle type--e.g., the saw-toothed grain beetle (Oryzaephilus surinamensis (L.))--and the flour beetles (Tribolium spp.) are capable of breeding in seed almost devoid of moisture. Flour beetles are not troublesome in dry seed, however, if the seed is clean and free from broken kernels, since the young larvae find it difficult to attack the undamaged seed.

Temperatures above 95° F. are not favorable for the development of most seed-infesting insects. Temperatures below 70° also greatly retard their development. A seed temperature of 65° prevents the reproduction of flour beetles, and 60° is approximately the lowest temperature at which the rice and granary weevils reproduce. Tyroblyphid mites are somewhat more hardy; they are reported to breed in seed kept between 40° and 50°, but only when the seed moisture is above 12 percent. Within the limits shown in figure 1, reproduction of the confused flour beetle (Tribolium confusum Duv.) in wheat increases with the increase in temperature, grain moisture, and amount of dockage.

Moisture Changes in Seed

In the dry climate of the Southwest seeds lose moisture rapidly, and therefore retain their viability longer than they do in the South and Southeast, where the high relative humidity of the air tends to maintain high seed moistures. In the North, where storage temperatures are lower, a low seed moisture content is not so vital. The relation between seed moisture and the relative humidity of the atmosphere is indicated in table 1.

Table 1.--Estimated moisture contents of seed (fresh basis) attained at different relative humidities of air[1/]

Kind of seed	Estimated moisture content of seed stored at relative humidity of--			
	45 percent	63 percent	73 percent	80 percent
Bean, kidney	9.0	12.0	14.0	16.0
Bean, lima	9.0	12.0	14.0	15.0
Beet	6.5	10.0	12.5	15.0
Cabbage	6.0	8.0	9.0	10.0
Carrot	7.5	10.0	11.0	12.5
Celery	9.0	11.0	12.0	13.5
Corn, sweet	9.0	11.0	12.5	14.0
Cucumber	7.0	8.5	9.0	10.0
Lettuce	6.0	8.0	9.0	10.0
Okra	10.0	12.0	13.0	14.5
Onion	9.0	11.0	12.0	13.5
Pea, garden	9.0	12.0	13.5	15.5
Peanut (shelled)	4.5	6.0	7.0	8.0
Pepper	7.5	9.5	10.5	12.0
Spinach	10.0	12.0	13.0	14.5
Tomato	8.0	10.0	11.0	12.0
Turnip	6.0	8.0	9.0	10.0
Watermelon	7.5	9.0	10.0	11.0

1/ From Toole, E. H., U. S. Dept. Agr. Leaflet 220, 8 pp., illus. 1942.

An estimate based on the assumption that insect attack will not be a factor in the maximum safe seed-moisture content of different kinds of vegetable seeds for satisfactory storage for a year is given in table 2.

Table 2.--Estimated maximum safe seed moisture contents for storage for 1 year at different mean temperatures of storage (approximate guide only)1/

Kind of seed	Maximum safe seed moisture content for average temperature of storage indicated		
	40°-50° F.2/	70° F.	80° F.
	Percent	Percent	Percent
Bean, kidney	15	11	8
Bean, lima	15	11	8
Beet	14	11	9
Cabbage	9	7	5
Carrot	13	9	7
Celery	13	9	7
Corn, sweet	14	10	8
Cucumber	11	9	8
Lettuce	10	7	5
Okra	14	12	10
Onion	11	8	6
Pea, garden	15	13	9
Peanut (shelled)	6	5	3
Pepper	10	9	7
Spinach	13	11	9
Tomato	13	11	9
Turnip	10	8	6
Watermelon	10	8	7

1/ From Toole (see footnote 1, table 1).

2/ Special precautions needed when removed to higher temperature. (See section on Cold Storage of Seed.)

Sources of Infestation

Most of the insect pests of seed are good fliers, and infestation may occur in the field before harvest. This is particularly true in warm climates, where the insects can survive the winter in the fields. Infestation in the field is not serious with most kinds of seed, but is of considerable importance in the production of seed of leguminous crops. These seeds are attacked in the field by bruchid beetles, and most of the species continue to breed after the seed is harvested and placed in storage.

Usually, however, infestation of seed occurs after it is harvested and placed in storage. The insect pests of stored seed are rather general feeders and occur everywhere. They breed in feed and grain supplies on farms and in nearly every type of food commodity and storage place used by man. Infestation results from temporary storage in bins or warehouses that are not thoroughly clean or that are near sources of infested materials.

Packaged seed that is carried over from one season to another is particularly susceptible to infestation by the Indian-meal moth. This moth, which is one of the most troublesome pests of stored seed, lays its eggs on or near the packages. The caterpillars, or "worms," that hatch from the eggs are exceedingly small and easily enter the packages at top corners where the gummed flap does not completely seal the package. The caterpillars "web up" the contents and when fully grown cut their way out through the sides of the package.

Preventive Measures

Prompt harvesting of seed will greatly reduce the opportunity for field infestation. Seed subject to infestation in the field should be treated as soon as possible after harvest, to prevent further damage to the seed already infested and to check the spread of infestation. Seed should be clean and should have as low a moisture content as possible. Storage at temperatures below 70° F. is desirable. Storage bins and warehouses should be kept scrupulously clean and free from old infested seed. Returned stocks of seed should be segregated and treated before being taken into storage warehouses.

Fumigation

Fumigation offers a rapid and effective method of destroying insect life in stored seed. If the proper precautions are taken, no damage to germination need be feared. Under certain circumstances, however, most fumigants are likely to lower the viability of some types of seed. If seed moisture is over 12 percent, or if the dosage or the exposure period is excessive, many fumigants will cause injury. Exposure periods should not exceed 24 hours. If bulk seed is treated, provision must be made to aerate it after 24 hours unless the fumigant used is known to be harmless under all conditions. Most bulk seed has

the faculty of absorbing and retaining fumigants for long periods; therefore, unless it is aerated the exposure period is automatically extended and serious germ injury may result. The effect of excessive dosages and exposure periods on the viability of seed corn fumigated with chloropicrin is indicated by the data in table 3.

Table 3.--Germination injury to seed corn of different moisture content when fumigated with different dosages of chloropicrin at 75° F. for various lengths of time

Dosage of fumigant per 1,000 bushels of seed	Period of exposure	Germination of corn with indicated seed-moisture content			
		10 percent	12 percent	14 percent	16 percent
Pounds	Hours	Percent	Percent	Percent	Percent
2	6	74	74	72	68
	12	71	75	69	70
	24	79	77	71	76
	48	74	70	63	65
	72	70	70	63	63
4	6	76	77	70	70
	12	75	71	61	65
	24	71	61	60	58
	48	76	56	55	56
	72	73	60	57	59
6	6	76	76	57	57
	12	70	75	61	58
	24	71	67	56	47
	48	71	59	53	55
	72	72	52	48	48
8	6	73	72	56	59
	12	71	69	54	55
	24	73	60	45	49
	48	71	56	44	46
	72	68	40	45	46
Check (untreated)	72	82	85	80	76

Fumigations may be conducted in bins, vaults, or warehouses. For warehouse and vault fumigation hydrocyanic acid, methyl bromide, or chloropicrin can be used at the rate of 1 pound to 1,000 cubic feet of space. No damage to germination need be feared from the use of hydrocyanic acid. If the moisture content is not over 12 percent, and if fans are employed to keep the vapors from forming layers near the floor, methyl bromide or chloropicrin may be safely used.

For the treatment of binned seed a 3:1 mixture of ethylene dichloride and carbon tetrachloride is recommended, at a dosage of 4 to 5 gallons per 1,000 bushels of seed, depending on the tightness of the bin and the type of seed being treated. This mixture does not appear to injure the germination of bulk seed regardless of the seed moisture, the dosage, or the exposure period.

The data in table 4 show that many of the common grain fumigants are safe to use if the moisture content of the seed is not over 12 percent and the dosage and exposure period are not excessive. Directions for applying these fumigants and precautions to be taken in handling them are given in Circular 369 and Farmers' Bulletin 1811 published by this Department.

Table 4.--Effect of various fumigants on the germination of wheat with a 12-percent moisture content when treated with the recommended dosages and exposed for 24 hours

Fumigant	Dosage per 1,000 bushels	Germination
		Percent
Calcium cyanide	15 pounds	94
	Gallons	
Ethylene dichloride + carbon tetrachloride (3:1 mixture)	6	94
Same plus methyl bromide 10 percent	2	93
Carbon disulfide	3	94
Same plus carbon tetrachloride (1:4 mixture)	3	95
1,1-Dichloro-1-nitroethane 3 lb. + carbon tetrachloride to make 1 gal.	1	95
Chloropicrin 3 lb. + carbon tetrachloride to make 1 gal.	1	89
Check (untreated)	--	98

Use of Naphthalene and Paradichlorobenzene

Napthalene and paradichlorobenzene crystals have been used extensively for the protection of seed. The recommended dosages vary greatly. A popular dosage is about 1 ounce of the crystals per bushel, although much heavier dosages are sometimes recommended. According to Roark and Nelson,[1/] the maximum weights of naphthalene and of paradichlorobenzene that can exist in vapor form in 1,000 cubic feet of space at 77° F. are 0.04 and 0.5 pound. Therefore, the small dosage recommended is more than sufficient to provide a saturated atmosphere. The crystals mixed with the seed give off vapors that are toxic to insects.

The effect of saturated atmospheres of these materials on the germination of seed corn of different moisture content was determined by storing seed for various lengths of time in 1-quart glass jars together with 1/4 ounce of the crystals. The results of this experiment, as shown in table 5, indicate that little injury to germination need be feared from naphthalene vapors if the seed-moisture content is not over 12 percent. Paradichlorobenzene vapors, however, cause considerable damage to germination even in very dry seed. Seed treated with either of these chemicals is rendered unfit for animal feeds, since there is an obnoxious odor and taste imparted to the flesh of animals and poultry fed treated grain and to the eggs laid by poultry so fed.

[1/] Roark, R. C., and Nelson, O. A. Maximum weights of various fumigants which can exist in vapor form in a 1,000 cubic foot fumigation chamber. Jour. Econ. Ent. 22: 381-387. 1929.

Table 5.--Effect of atmospheres saturated with paradichlorobenzene and naphthalene on germination of seed corn containing different amounts of moisture when exposed for various lengths of time

Chemical	Period of exposure	Germination of corn with indicated seed-moisture content			
		10 percent	12 percent	14 percent	16 percent
	Months	Percent	Percent	Percent	Percent
Paradichlorobenzene	1	86	85	47	0
	2	62	59	19	4
	3	61	38	12	0
	4	49	35	23	0
	5	43	29	9	0
	6	17	10	0	0
	7	35	15	1	0
	8	47	14	0	0
	9	14	14	0	0
	10	0	0	0	0
	11	0	0	0	0
Naphthalene	1	90	94	94	93
	2	93	94	91	91
	3	98	97	92	79
	4	95	94	81	51
	5	93	88	64	0
	6	91	79	56	0
	7	95	88	53	0
	8	96	82	32	0
	9	95	75	29	0
	10	95	75	14	0
	11	97	75	19	0
Check (untreated)	1	93	94	94	91
	2	96	95	96	73
	3	96	97	92	59
	4	97	95	74	21
	5	99	96	85	58
	6	98	96	46	34
	7	97	94	33	5
	8	92	92	15	9
	9	98	96	55	6
	10	98	92	36	0
	11	96	95	24	0

Use of Dusts for Protecting Seed

Of the several methods available for protecting seed from insect attack, mixing seed with a dust provides the most economical long-time protection. The treatment is simple, nonhazardous to the workman, and noninjurious to the seed.

Many dusts have been proposed and employed for this purpose. Some of these dusts are known to be active insect poisons, while others apparently affect the insects physically rather than chemically. In the following discussion the poisonous dusts are designated as chemically active, and those which appear to have only a physical effect on the insects are referred to as chemically inert. Chemically inert dusts are those which are thought to be effective by causing breaks in the waterproof fatty covering of insects, so that the dusted insect dies as a result of the evaporation of excessive amounts of body moisture. Owing to their mode of action, the effectiveness of inert dusts decreases as the moisture content of the seed increases over 12 percent. The effectiveness of chemically active dusts is not reduced by seed moisture.

Of numerous chemically inert dusts tested, magnesium oxide has been found especially well adapted for protecting seed from insects. Its insecticidal value against stored-product insects was first recorded by F. Zacher in Germany in 1929. It is a nonpoisonous dust used medicinally as a remedy for stomach acidity. Many types of magnesium oxide are available on the market, and extensive laboratory tests have shown that those having a particle size of 1 micron or less afford excellent protection when mixed with seed at the rate of 0.1 percent by weight. In general the finer the dust the more effective it is. In addition to its killing effect, magnesium oxide has a distinct repellent property and seeds treated with it are rarely invaded by insects. Treatment with this dust is not only effective and inexpensive, but also imparts a clean and attractive appearance to seed (fig. 2). Magnesium oxide can be purchased in large quantities at a cost of approximately 3 cents per pound, and in smaller lots at correspondingly higher prices. A list of firms handling magnesium oxides will be found on page 13.

Of chemically active dusts tested, those containing technical DDT are the most promising. They are effective against most of the common pests of stored seed, regardless of its moisture content. DDT is best used in combination with a carrier dust, such as magnesium oxide or pyrophyllite. The carrier, by increasing the volume, insures adequate distribution over the seed. An effective and inexpensive dust consists of 3 percent of DDT in magnesium oxide. By using this mixture advantage may be taken of the repellent effect of the magnesium oxide as well as the insecticidal though nonrepellent qualities of the DDT. Neither product has any deleterious effect on germination, as indicated by the data in table 6. Commercially prepared mixtures containing 3 percent of DDT in pyrophyllite or other carrier will probably soon be available, and it may be more convenient to use such mixtures.

Table 6.--Effect of magnesium oxide and DDT dusts on the germination of wheat of different moisture content

Dust	Period of exposure	Germination of wheat with indicated seed-moisture content						
		12 percent			14 percent			16 percent
		Percent of dust mixed with seed						
		0.05	0.1	0.2	0.05	0.1	0.2	0.2
	Months	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Magnesium oxide	1	92	90	89	88	90	93	92
	2	92	92	93	91	90	87	84
	3	90	90	90	85	87	92	77
	4	88	93	94	86	84	83	78
	5	96	93	95	76	84	83	75
	6	95	95	90	82	83	84	68
	7	96	98	90	79	89	82	66
	8	97	93	93	80	81	77	66
	9	96	93	91	78	81	77	68
	10	96	93	94	78	81	77	71
	11	97	97	97	86	86	87	—
	12	97	97	97	86	86	87	—
DDT, 3 percent in pyrophyllite	1	91	91	90	—	—	93	89
	2	95	88	90	—	—	84	74
	3	93	90	90	—	—	89	78
	4	86	90	95	—	—	90	78
	5	89	92	95	—	—	89	65
	6	96	94	95	—	—	90	67
	7	93	93	91	—	—	90	64
	8	96	96	95	—	—	88	63
	9	97	94	96	—	—	86	60
	10	97	94	96	—	—	86	59
	11	98	94	96	—	—	—	—
	12	98	94	96	—	—	—	—
Check		(No dust of any concentration applied)						
	1		87			88		91
	2		86			82		86
	3		93			87		70
	4		87			75		62
	5		94			71		51
	6		93			65		41
	7		93			64		38
	8		93			60		31
	9		95			65		—
	10		94			65		—
	11		94			68		—
	12		94			68		—

For the treatment of seed in bulk a seed-treating machine will be found most practicable. With this method it is suggested that magnesium oxide be applied at the rate of 1 ounce per bushel of seed, or the 3-percent DDT dust at the rate of 1/2 ounce per bushel.

Seed that has been treated with any of these dusts should not be used as food for man or livestock. DDT in particular is poisonous to warm-blooded animals as well as to insects.

Cold Storage of Seed

Since insects are inactive below 50° F., storage of seed at temperatures between 40° and 50° will prevent insect damage. Seed moisture should be as low as possible. As mentioned previously, mites may cause damage at such temperatures if the moisture content is over 12 percent. According to Toole,[2/] "even at low temperatures contaminating fungi may develop at humidities approaching 80 percent and cause further injury to the seed. **** the seeds of onion, sweet corn, celery, watermelon, and pepper showed appreciable loss of viability in 6 to 9 months when stored at 80 percent humidity at a temperature of 50° (F.)" The same author suggests that precaution should be taken in the use of cold storage, since "It has been found that seeds removed from cold storage with a high moisture content and subjected to high summer temperatures deteriorate so rapidly that in a few weeks the benefit of holding in cold storage may be lost." He recommends that "Unless the seed is to be used at once after removal from storage, the moisture content should be determined and, if the moisture is above the safe limit (see table 2) for the expected temperature, the seed should be dried carefully to a safe moisture content."

Use of Heat

Insect infestation in seed may be destroyed by high temperatures. A temperature of 140° F. for 10 minutes is fatal to all stored-seed insects exposed to it. Such a temperature is not likely to injure germination, unless the seed is low in vigor or high in moisture content. Newly harvested seed with a high natural moisture content should not be subjected to high temperatures until the excess moisture is removed. Any method of applying the heat that will provide for the uniform heating of all the seed is satisfactory.

2/ See footnote 1, table 1.

Procurement of Magnesium Oxide

The accompanying list of manufacturers and distributors of magnesium oxide is included for the information of the users of this circular, without given or inferred guarantee of the reliability of the firms or endorsement of their individual products. No attempt has been made to make the list complete, and no discrimination is intended or implied against firms whose names are not listed. When ordering magnesium oxide, it is essential to specify that the particle size should not exceed 1 micron.

American Cyanamid and Chemical Corp., 30 Rockefeller Plaza, New York 20, N. Y.

Dow Chemical Co., Midland, Mich.

General Magnesite and Magnesia Co., 2960 East Venango St., Philadelphia, Pa.

Goldwynne Chemical Corp., 420 Lexington Ave., New York, N. Y.

Marine Magnesium Products Corp., South San Francisco, Calif.

Michigan Chemical Co., St. Louis, Mich.

Westvaco Chlorine Products Corp., 405 Lexington Ave., New York, N. Y.

Summary

Stored seed should be kept cool and dry in order to protect it from serious insect damage and to preserve its viability for the longest possible period. Storage of seed at temperatures of below 60° F. will prevent serious insect injury, and heating of dry seed to 140° for 10 minutes destroys insect infestation. Fumigation with any of the common grain fumigants also destroys insect infestation, and no material damage to germination need be feared if seed moisture is not over 12 percent, exposure periods are not longer than 24 hours and the seed is aerated immediately thereafter, and dosages are not excessive. A magnesium oxide dust mixed with the seed at the rate of 1 ounce per bushel or a dust containing 3 percent of DDT in a suitable carrier, applied at the rate of 1/2 ounce of the mixture per bushel of seed, affords effective and inexpensive long-time protection against infestation by insects. Seed treated with any of these dusts should not be used as food for man or livestock. DDT is poisonous to warm-blooded animals as well as insects.

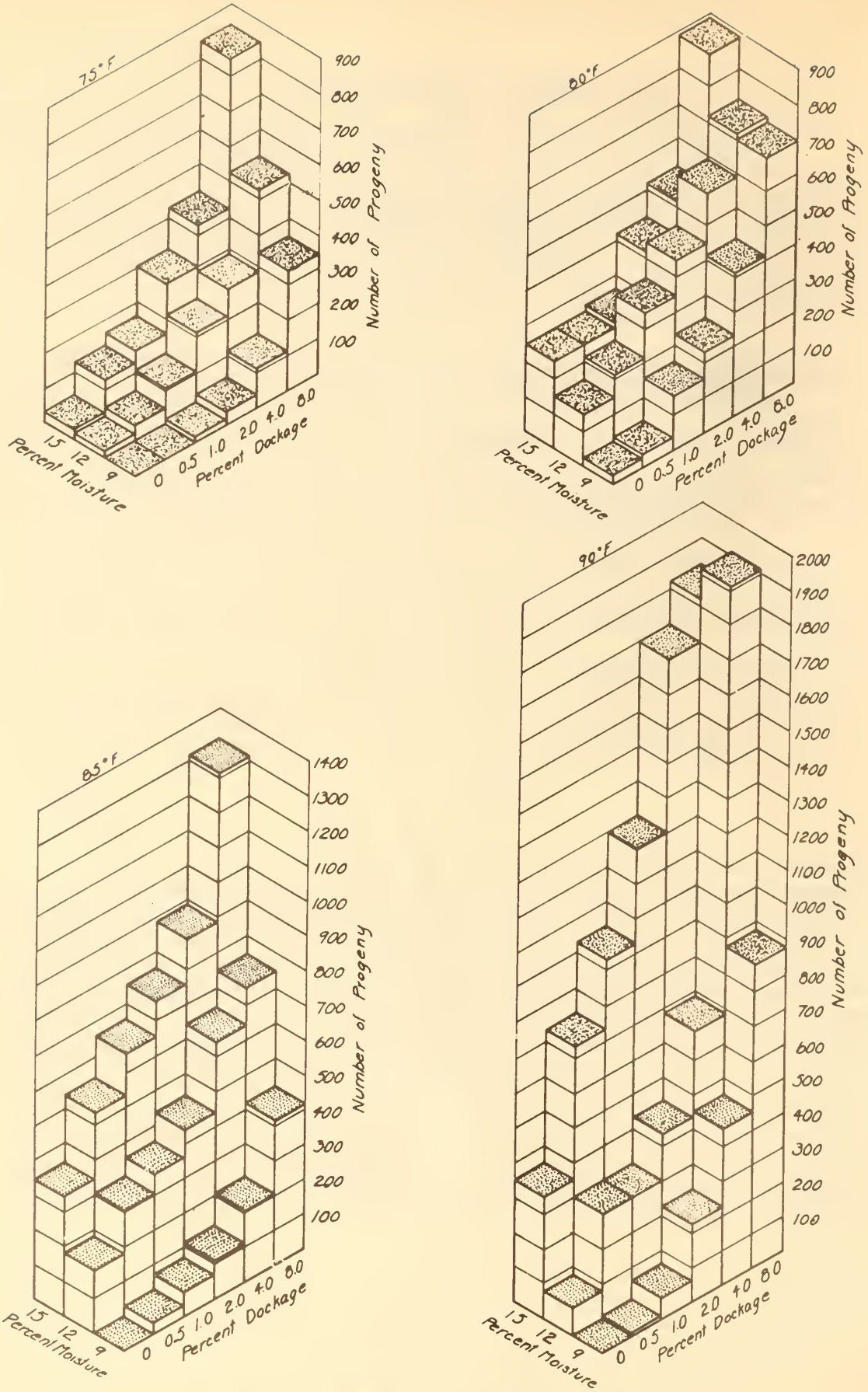

Figure 1.—Effect of variations in temperature, moisture, and dockage present in wheat on the reproduction of 25 confused flour beetles over a 19-week period.

Treated Untreated

Figure 2.--Two lots of sunflower seed after exposure to insect infestation for 1 year. Seed on left was treated with magnesium oxide and remained undamaged. Untreated seed on right was almost completely destroyed.

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CORRECTION

E-677. Please substitute the attached sheet for page 15, recently mailed to you.

Treated Untreated

Figure 2.--Two lots of sunflower seed after exposure to insect infestation for 1 year. Seed on left was treated with magnesium oxide and remained undamaged. Untreated seed on right was almost completely destroyed.